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The performance of five volunteer tests subjects wearing a standard cold weather cold weather military uniform and three different gloves was compared during treadmill walking (120 minutes), sitting (125 minutes) and hand conductance or "contact" (60 minutes). Chamber conditions were -6.7°C (20°F) T_a and 1.1 $m \cdot s^{-1}$ wind speed. The sitting tests were repeated at 0°C (32°F). Contact tests were repeated with wet gloves. Rectal and finger temperatures, heart rate, and endurance times were measured. The results indicate that the new leather shell is more affected by external moisture than the standard shell. Keywords;

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COMPARISON OF LIGHT DUTY GLOVES WITH NATURAL AND SYNTHETIC MATERIALS UNDER WET AND DRY CONDITIONS

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The performance of five volunteer test subjects wearing a standard cold weather military uniform and three different gloves was compared during treadmill walking (120 minutes), sitting (125 minutes) and hand conductance or "contact" (60 minutes). Chamber conditions were -6.7°C (20°F) T_a and 1.1 $m \cdot s^{-1}$ wind speed. The sitting tests were repeated at 0°C (32°F). Contact tests were repeated with wet gloves. Rectal and finger temperatures, heart rate, and endurance times were measured. The results indicate that the new leather shell is more affected by external moisture than the standard shell.

INTRODUCTION

The primary US military issue glove for general cold weather wear is a light duty glove that is slightly modified from that which was issued to US troops in WWII (Richardson and Allan, 1948). The glove consists of a durable leather shell worn over a separate wool/nylon knit liner. The long duration of this basic light duty glove design can be attributed to the functional utility and effectiveness of the two layer, leather shell/knit liner design.

Despite the historical success of the glove, considerable dissatisfaction has been expressed regarding the issue glove. Two factors directly communicated to the authors by military users which contribute to the dissatisfaction are 1) perceived failure of the glove to provide adequate thermal protection, particularly if the experience was personal or directly affected unit efficiency and 2) dissatisfaction with the use of traditional materials, particularly wool, when recently developed synthetic materials claim improved properties and eliminate allergic reactions to wool.

For organizations, including military unit, police and public utilities, which must function under adverse weather conditions, the ultimate criterion for all clothing is an individual's ability to endure and perform the assigned mission. Comparisons of different handwear based on

measurements of individual performance are a critical element in decisions regarding handwear. The methods used to evaluate handwear and other cold weather clothing items are therefore important and merit a thorough description.

The primary purpose of the present study was to compare performance of subjects wearing three light duty gloves. The test standard was the present issue LD glove consisting of a leather shell and wool/nylon insert. Two additional configurations combined a new leather shell design with two different inserts of hollow-core polyester material. One insert (P1) is a simple knit insert with a smooth palm, while the other insert (P2) is also knit of the same synthetic material but the palm area is covered with circular projections to prevent slippage when the insert is used alone as an anti-contact glove.

Preliminary measurements of dry insulation (I_t) were conducted for each of the gloves on a newly constructed nine-region aluminum hand model (Santee, unpublished). Initial results indicate that I_t values derived with this hand model are approximately 0.10 clo less than values measured on a previous copper hand model. The thermal insulation values obtained were 0.124 $m^2 \cdot K \cdot W^{-1}$ (0.80 clo) for the LD glove and 0.118 $m^2 \cdot K \cdot W^{-1}$ (0.76 clo) for both the P1 and P2 gloves.

In handwear studies, the insulation values of the total clothing system are also important (Vanggaard,1988). For this study, the layered uniform consisted of cotton/wool long underwear, battle dress uniform (BDU), field jacket with polyester liner, pile cap, cotton/wool cushion sole sock and leather combat boots plus the gloves. The preceding clothing items are common fall and winter clothing for the military, although the long underwear is usually not worn until the colder part of the winter and other headgear may be substituted for the pile cap.

METHODS

The relative protection provided by the standard and prototype gloves was determined by quantifying the performance of five volunteer, male test subjects. Volunteer subjects were recruited from the local military population. Subjects read and signed an informed consent agreement after receiving a verbal briefing. Subjects were medically screened and received a thorough medical examination prior to clearance for participation. All testing was in accordance with AR 70-25 and the USARIEM type protocol. Their performances were determined during three activities.

On different test days, subjects walked on a treadmill at 1.34 $m \cdot s^{-1}$ (3 mph) for 120 minutes (plus a 5 min baseline), sat for 125 minutes, or participated in a contact simulation for 60 minutes (plus a 5 min baseline). All three test activities were conducted at a chamber air temperature of -6.7°C (20°F) and a wind speed of 1.1 $m \cdot s^{-1}$ (2.5 mph). The sitting tests were replicated at a second chamber temperature, 0°C (32°F).

The contact simulator was developed as a test device which produces a controlled, replicable measure of conductive heat

loss from one hand. The simulator is a generic modification of a pump simulator specifically built for testing fuel handlers gloves (Santee, et. al., 1988). The device consists of an adjustable stand with a plastic envelope mounted on an aluminum plate at waist level. The envelope is filled with propylene glycol which is circulated through a heat exchanger to maintain the liquid at chamber air temperature. When a subject pushes against the envelope with sufficient force (9.5 kg or 21 lbs), a pressure sensitive switch activates a timer. The timing device is set to signal when the subject maintains contact for 2 minutes, then a 1 minute rest period is signaled before restarting the push/rest cycle. If the subject does not press with sufficient force, a light on each stand indicates that the timer is not operating. The push cycle duration is based on the actual time that the switch is activated, so if the subject fails to maintain contact with the envelope with sufficient force to activate the timer the cycle timer does not countdown towards the rest period. A total of four devices were assembled, so multiple subjects were tested during one experimental session.

All initial tests were with dry gloves. The contact simulation tests were repeated with wet gloves after the dry glove tests. The glove on the pushing hand was wetted by having the subject remove sponges from a basin and squeeze out enough water to fill five 200 ml beakers. The objective was to simulate working with a wet substance, such as a wet canvas or snow, and to thoroughly work the moisture into the seams of the gloves. The walking and contact simulation activities were preceded by a 5 min standing baseline.

Measurements included heart rate, rectal temperature, nine skin surface temperatures including the lateral nail beds of the middle and little left and right fingers and the left big toe. Safety monitoring standards included removal of the subject from a test session if a heart rate of 180 bpm was sustained for 5 minutes, the rectal temperature dropped to 35.5°C (95.9°F), a skin surface temperature dropped to 5.0°C (41°F), a test observer inside the chamber removed the subject or the subject voluntarily exited the chamber.

The basic method for statistical analysis was analysis of variance with repeated measures (SPSS, 1988). The significance of relationships between individual pairs was verified by post hoc Tukey's t-tests at the 0.05 significance level (Bruning and Kintz, 1977). Physiological measurements included heart rate, rectal temperature and four finger temperatures. Dependent variables were total activity time (ET) for walking (max 120 min), sitting (125 min max) and contact (max 60 min), cumulative contact time (CT, max 40 min) and the average rate of change for four (walking and sitting) or two (contact) finger temperatures. By averaging the finger temperatures, the effect of cold-induced vasodilation (CIVD) on finger temperature variability is dampened.

RESULTS

Figure 1 demonstrates the finger temperature responses of a subject at -6.7°C (20°F) during walking, sitting and dry contact test activities. Subject physical parameters are presented in Table 1. The test results are summarized in Tables 2-4.

The results indicate that no significant difference in subject endurance time or change in finger temperature between dry gloves with polyester or wool inserts can be determined on the basis of this study. When the wet and dry contact simulation results were combined for statistical analysis, the results indicated overall significant differences between wet and dry gloves for ET, CT and ΔT/hr. For ET and CT, there were also significant differences between the wet and dry conditions for the two synthetic gloves (P1 and P2). The standardized changes in mean finger temperature (2 finger mean, right hand only; 4 finger mean left and right hands) were significantly different overall between wet and dry conditions and overall between LD and P1. In specific pairs there was a significant difference between the wet and dry conditions for P1. For the change in four finger mean temperature there was also a significant difference between the LD and P1 gloves in the wet condition.

Figure 1. Average of two right finger temperatures versus time for walking, sitting, and dry contact activities (subject 1)

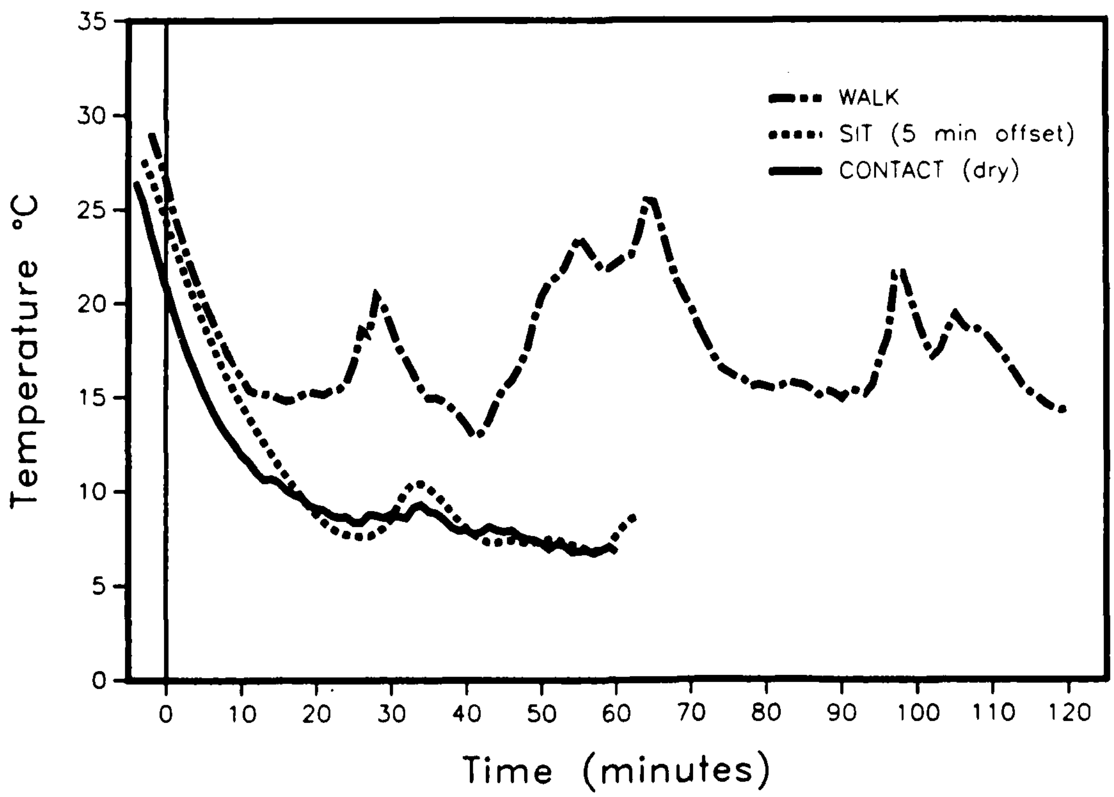

Table 1. Average physical parameters of volunteer test subjects (n=5)

subject	height (cm)	weight (kg)	age (years)	A_D[1] (m^2)	body fat[2] (%)
1	172	74.6	20	1.88	15.2
2	178	79.3	21	1.97	15.1
3	175	75.6	23	1.91	17.0
4	170	62.7	19	1.73	9.3
5	166	66.0	26	1.74	15.7
mean	172	71.6	22	1.85	14.5
s.d.	5	7.0	3	0.11	3.0

[1]Dubois surface area (Dubois and Dubois, 1916)
[2]skinfold measurements (Durnin and Womersley, 1974)

Table 2. Endurance times (ET, min) for all activities

	light duty glove (LD)	test glove plain (P1)	test glove textured (P2)
walk (-6.7°C)[1]	85[2]	120	120[3]
s.d.	41	0	0
sit (-6.7°C)[4]	82	72	81
s.d.	21	15	36
sit (0°C)[1]	125	125	117
s.d.	0	0	9
contact (dry, -6.7°C)[4]	57	56	54
s.d.	5	4	13
contact (wet, -6.7°C)[4]	47	27	32
s.d.	19	20	20

[1]n=4, [2]includes mean of two runs for subject removed for non-thermal factor, [3]n=3 [4]n=5

For ET and CT, the differences between wet and dry gloves were significant ($p \leq 0.05$) overall and specifically (Tukey's t-test, $p=0.05$) between P1 and P2. For the change in finger temperature ($\Delta T \cdot t^{-1}$ or $\ln(\Delta T \cdot t^{-1})$), there were significant overall differences between dry and wet gloves, and between dry and wet for the P1 glove. The rate of temperature decline for the LD glove was significantly less then the decline for the P1 glove for both the combined wet-dry and wet only data sets. The results indicate that the glove with projections

(P2) was not significantly different from the regular issue LD. There were no significant differences between dry gloves with natural or synthetic liners. The results also indicate that the performance of subjects while wearing the P2 gloves with the grip projection was intermediate between LD and P1, but not significantly different from either glove. During the wet testing, subjects indicated a highly variable degree of moisture penetration inside the glove. Based on those results, the lack of significance between LD and P2, and no measured difference in insulation between P1 and P2 which have liners knit of the same polyester, it was concluded that the differences between wet gloves were possibly due to water leakage through the different shells.

Table 3. Contact times for wet and dry contact activities

	LD	P1	P2
dry contact	36.74	36.09	34.89
s.d	3.18	4.00	9.00
wet contact	30.40	17.78	20.46
s.d.	12.29	12.25	12.60

Table 4. Standardized finger temperature loss for sitting and contact activities (ΔT/hr)

	LD	P1	P2
sit (-6.7°C)[1]	13.46	10.54	12.92
s.d.	2.57	3.36	6.80
sit (0°C)[1]	8.39	8.46	8.09
s.d.	0.61	2.27	2.66
dry contact[1]	15.84	17.83	15.79
s.d.	3.20	3.09	2.77
wet contact[1]	21.22	44.71	35.10
s.d.	9.42	19.33	13.62
dry contact[2]	17.14	18.64	16.07
s.d.	2.87	2.73	2.59
wet contact[2]	22.01	46.56	32.80
s.d.	10.04	25.03	14.19

[1]four finger (little and middle finger, right and left hand)
[2]two finger (little and middle finger, right hand only)

DISCUSSION

A military focus has been an important traditional resource for the evaluation of cold weather clothing. Driven by the pragmatic needs of troops in the field, a combination of extensive, long term testing programs and cumulative field experience has resulted in practical, economical cold weather clothing. Both the need to ensure that the clothing will meet the requirements of soldiers in the field, especially in terms of durability in a tactical situation while providing adequate thermal protection, and the extensive costs required to build and maintain an adequate clothing inventory result in a conservative approach to clothing development. Conversely, the growth in outdoor winter recreation created a marketplace that stimulated the development of new synthetic insulation materials for clothing. However, the requirements of the military, especially in terms of durability, are not the same as those of recreational users (Hedblom, 1965). Soldiers in the field often endure longer exposures to cold and subject their clothing to heavier use and wear than the majority of recreational users.

The results of this study indicate that the sedentary or sitting test method, yielded no better effects than by the use of the contact method for evaluation of dry gloves in this study. In a previous test (Santee and Endrusick, in preparation), the contact test allowed discrimination between two gloves of nearly equal insulation. That prior test included a walking activity, but not a sedentary activity. The sedentary test represents the definitive "worst case" for handwear testing, with the lowest levels of heat production and vasoconstrictor stimulation. It is also longer in duration and requires longer subject exposure to low temperatures than the contact test. Actual situations which might require such a low sedentary level of activity during cold exposure include military personnel holding defensive positions, occupants of unheated vehicles, and heavy equipment operators. The contact test is a generic, "worst case" simulation of scenarios such as material handling or vehicle maintenance which require prolonged contact with cold objects or surfaces in unheated areas.

Summary

The results of this study demonstrated no significant difference in the performance of test subjects between the three dry gloves. The synthetic knit liner can be adequately substituted for the wool/nylon liner with no significant loss in thermal protection. There is no significant change in thermal cost related to the improved textured gripping surface of the P2 glove. The results also indicate that the new leather shell is more affected by external moisture than the standard shell.

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Disclaimer

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